Towards location- and orientation-aware gaming: Research on Location-based Games with additional compass features

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Abstract

Location-Based Games have been around for over a decade. Despite never reaching a large audience, the increase in technology in mobile devices offers great possibilities for the genre. New features in mobile devices can be combined with Location-Based Games, which already use the GPS feature of mobile devices, to extend this genre. An example of such a combination is the addition of a compass to create an Orientation-aware Location-Based Game. Current mobile devices offer the components, but have not been examined to such an extent that the feasibility of these type of games is clear.

In this master thesis we will look at this feasibility by first assessing the necessary components. When the capabilities of those components are known a straightforward game with location- and orientation-aware properties is examined in a user study. From the results, we conclude that current mobile devices include sensors that, despite data with inaccuracy, still can deliver a sufficient accuracy for some purposes in a location- and orientation-aware application. The users responded very positively to the game and had little trouble in carrying out its tasks. This provides us with a clear step towards developing games for mobile devices that include the location and orientation features in its game design.

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1 Introduction

In the year 2000, the Global Position System (GPS), which until then was restricted to military use, became available for regular use. Within days a game that incorporated GPS into the game play was launched. That game is called GeoCaching and is still being actively played today. Such a game is known as a Location-Based Game (LBG). The game is very static, only letting players search for fixed GPS locations in the real world, where a container, called a "cache", is hidden. With the rise of smartphones that also included a GPS receiver, a larger audience could be reached and more complex games were introduced, all with the similar feature of incorporating the player's location in the real world as part of the game mechanism.
Besides the GPS receiver, smartphones also started to include other built-in sensors that measure motion, orientation, and various environmental conditions. Incorporating these sensors makes it possible to create applications that are highly aware of a user's surroundings. Combining sensors and incorporating them in games will allow us to create more complex and interesting games that are aware of aspects of the player or its surrounding.
One such combination is that of a compass incorporated in a LBG. This would make the device orientation- and location-aware. With such a combination we can envision a type of shooter game where one or multiple users use the compass to aim and shoot at targets or other players, while the GPS receiver tracks the position of the players. While this sounds interesting, the different sensors could cause some issues. For example, the sensors could suffer from inaccurate and imprecise data, or have a too high latency. A goal of this thesis is to research the feasibility of such a game. In order to learn about the feasibility we first must assess how the necessary components work individually during experiments. In a later stage we must look at how the combination of components will play out. Eventually we create an application with the technologies and let users play with it in a user study, before we draw a conclusion about its feasibility.
Due to its open-source property and easy accessibility we limit ourselves to the Android platform, and only use mobile devices running Android during our experiments.

1.1 Overview

In this thesis we will first discuss the history and timeline of existing location-based games in Section 2. This will give an overview of how the genre originated and in what direction the development is going. In Section 3 related work will be discussed, along with the research questions that will be answered in this thesis. This will outline what already has been examined together with why we need to ask certain substudy questions in our attempt to answer our main research question. Section 4 will discuss the hardware components in mobile devices that are relevant for our implementation, and how certain features are implemented. The first experiments of this thesis will be described in Section 5. The first experiments will test sensors and components of mobile devices. In this section the designs of these experiments have will be laid out, together with the results from the experiments. The second experiment will be discussed in Section 6. This will outline the design of the implementation for the user study and how the user study has been set up, together with the results from the study. In Section 7 the results will be discussed and conclusions about our research questions will be drawn. Finally, the future work will be discussed in Section 8.

2 History and Timeline of Location-Based Games

Location-Based Games (LBG) are games that incorporate the user's location in the real world (RW) as a gaming mechanism. Actions performed by the user in the RW influence the progress of the game and often affects the virtual world (VW). When a GPS device is capable of displaying a VW, it provides a Mixed Reality experience. LBG's have been around since the Global Positioning System (GPS) became available for regular use on May 2, 2000. Before that time the signal was purposely scrambled and only available for military use[2]. The first and well known LBG is GeoCaching, which originated on May 3, 2000[3], and lets players search for hidden "caches" that have been hidden in the RW. Players can get the location of a cache in GPS coordinates and try to find it. Upon finding a cache they are supposed to sign a log that is contained by the cache, and sometimes offer items to trade. To this day GeoCaching is still played by many people all over the world [4].

In 2001 and 2003, a company called Blast Theory spawned the games Can You See Me Now? (CYSMN)[5] and Uncle Roy All Around You (URAAY)[6]. These games are chase games played in a city, and combined online with RW actions. In CYSMN online players controlled an avatar on a 2D map of a real city, where actual professional performers ran through the city in an attempt to capture the avatar. A player was captured when their online location matched the location of a runner. In URAAY players in the RW were in contact with online players through text and audio messages and needed to help or hinder each other in succeeding in their goals. These games are already more dynamic than GeoCaching, due to that the attributing GPS locations are constantly changing and regular updates need to be shared between the users.

Early LBG are often based on existing games. For example, treasure hunt games were the inspiration for GeoCaching, while regular chase games inspired CYSMN and URAAY. Another example is PacManhattan[8], which saw the light in 2004. This game, based on the original Pac-Man from 1980 [7], had people running around in Manhattan where one player, the *Pac-Man*, attempted to collect "dots", while other players, the *Ghosts*, tried to corner the Pac-Man player. Even though this game is classified as a LBG, it did not really use the GPS locations of the players. Instead additional people, the "controllers", were necessary to constantly update the player's locations, as they were in contact with the players using cell phones. In 2011 a game called PacMap[9] was released. The game offered a RW version of the original game, where the map in the VW was based on information from Google Maps. The player had to actually move in the RW to get the virtual dots, while avoiding the virtual ghosts. This is another example of how RW actions can influence the VW. It also sparked a debate about the danger of such games. Especially this game encouraged players to run at high speed through cities, while dividing their attention between their surrounding and the device's screen to receive feedback about their progress. Meanwhile it has been taken offline due to legal issues. An even more pervasive Pacman-based LBG was Human Pacman[10]. The game, designed by a research institute called Mixed Reality Labs, added Augmented Reality (AR) to the gaming experience, requiring extra technology in the form of a Head Mounted Display and motion sensors. The dots where not only visible in the VW, but also in the Augmented World (AW) through their displays, giving an even more intense sense of mixed reality. Where PacMap was a single player game, allowing the player to only be pacman, Human Pacman has players in the role of either Pacman or one of the ghosts, adding a multi-player aspect.

Most of these games, except for GeoCaching, are temporary and local games, and required special events to gather people to play the games. Geocaching is an early example of an ongoing game, but most ongoing games arose when internet and mobile technologies improved. The ongoing games are often Massive Multi-player Online (MMO) games, allowing players over the entire world to play the game simultaneously. An example of a popular ongoing LBG is FourSquare[11]. This game lets people "check in" at real places in the world in order to become the mayor of a location, which is the person who checked in the most at that location. Next to the game aspect of the application, it is also used for a user generated content database containing information of numerous real world venues. FourSquare can be described as a sort of "turf war" game, where players try to take over VW locations by actually visiting their RW counterparts as often as possible. Other examples of turf war games are the in

2012 launched TurfWars[13], or Google's 2013 Ingress[12], which lets people all over the world battle over RW areas, or in the case of Ingress over portals based on RW landmarks. This type of games does not necessarily have to be ongoing. A temporary example is MapAttack! by the company Geoloqi[14], which lets two teams compete over virtual points placed on a virtual map based on their RW location. Since it is not ongoing, it requires a planned event to play the game.

A next notable step in development is an ongoing LBG where the VW is based on even more information from the RW. LBG's quickly incorporated information from map data providers such as Google Maps, but these days even more information is available for use in LBG's. Google's Ingress, for example, correlates the density of its portals to population density. A better example is Tiny Tycoons (2013)[18] from the company The Tap Lap. Its VW is based on the real world combining map and venue information from the FourSquare content database. It allows players to buy, manage, and upgrade VW venues based on RW locations. The basic gameplay is similar to FourSquare's gameplay, letting players own venues which they have visited the most in the RW, but adds a gameplay layer where they can modify and play with their venues in the VW. With more and other data providers, such as Google Places[15] and Factual[16] becoming available, it is likely that more impressive virtual worlds will be created inspired on the actual world. The games will no longer be only location-based, but also aware of a player's environment. An example of a more location-aware game is CodeRunner[17]. This game emerges the player in an espionage adventure with a story line based on the RW around the player. For example, players can be sent to actual hotels near them to 'hack' their security camera's.

Another branch of LBG research is focused on smaller scale LBG's. Most of the provided examples need additional features, such as a server or information from external services such as Google Maps. AT&T researchers introduced the iTron Family in 2012[19], a set of LBG's that uses nothing besides mobile devices with GPS. No additional infrastructure is necessary since the entire game works on a peer-to-peer connection. The games are based on players who leave a trail in the VW by moving around in the RW. Their devices will show a map of their surroundings and the trails that have been created by the users. With this mechanism several games can be played. A competitive game inspired by *Snake* and *Tron* has players moving around in order to survive the longest without hitting a trail. Another game lets players work together by drawing a sketch using their trails. Additional elements to the VW create possibilities for more games, such as the *Pits of Doom* where the VW shows where "pits" will appear and players must avoid them. This last type of LBG has the advantage that it can be played anywhere and anytime, without the need for additional infrastructure or resources.

With advancement in the required technology and more available resources, both the discussed branches of LBG's are expected to deliver increasingly more interesting games. Future ongoing and location-based games might immerse players in a very mixed reality, with a virtual world completely based on the current surroundings of the player. Future Small scale LBG's could let players compete with each other in games that require no additional infrastructure besides their mobile devices.

Despite not having hit the consumer market yet, a next advancement in LBG's could be games with the addition of other features of mobile devices into the gaming mechanism, such as a digital compass.

3 Related Work and Research Questions

The goal of this thesis is to investigate the possibilities of smartphone games where the location receiver and digital compass are contributing components to the game. These games are location-based and orientation-aware. As discussed in Section 2, many Location-Based Games already exist. LBG's that are also orientation-aware do not seem to exist to the best of our knowledge. In an attempt to work towards such games we will set about to answer the following research question:

- What is the feasibility of an Orientation-Aware Location-Based Game?

While conducting our research to answer this question, we will have to answer several other substudy questions as well. They will be discussed in this section, together with related work on the corresponding subjects.

3.1 GPS

GPS is widely and actively used in many applications and by many users, ranging from consumer to military use. With a tradeoff between accuracy and costs, many different devices exist, resulting in a wide spread of accuracy between available devices. Consumer-grade devices cost less but suffer from more inaccuracy than those for military purposes. The accuracy of those devices is very critical and has therefore been examined many times for different devices, purposes, locations, and other influencing factors.

Performances between recreational and mapping grade GPS receivers were compared by Weih et al.[20] in their research. They concluded that mapping grade devices outperformed recreational devices, but that users of recreation devices still could expect an accuracy of 2.52 to 5.52 meters when used in a clear, unobstructed environment. Anderson et al.[21] also compared recreational with more professional devices in a range of forest conditions. They concluded the recreational devices to be accurate between 3 to 7 meters, while professional devices were generally accurate to within 1 meter.

Both researches also showed that with an increase in obstacles in the environment surrounding the device, such as near-buildings, trees, or foliage, the error for both types increased, but especially for the recreational grade. That a GPS receiver performs at its best in unobstructed environments is also shown in the work of Sigrist et al.[22], the work of Wing[23], and the work of Pirti[24], who each researched the impact of forest canopy on the quality and accuracy of the GPS signal, by examining the performance of devices in a variety of forest environments.

Another influencing factor was shown by Kos and Brčić[25], who showed that for GPS receivers in smartphones weather conditions also influence the performance.

Recent generations of mobile devices all include GPS receivers. These generations of devices will be used during this project. In mobile devices the tradeoff between cost and accuracy becomes even more evident, as it requires even smaller chipsets in already expensive devices. Preliminary studies who compared smartphones with GPS devices, concluded that smartphones could be used as a capable GPS device, and are a viable alternative to an expensive dedicated GPS device for small-scale research. This was concluded by Klimaszewski-Patterson [26] who compared a HTC android device with a dedicated GPS device, and in the work of Menard et al.[27] who compared three different smartphones with a vehicle device tracker, and despite a difference in the performance between the devices themselves, they concluded that all the devices are acceptable alternatives for tracking devices. Each smartphone was accurate within 10 meters 95% of the time. More research shows that GPS accuracy is also highly dependent on the type of device and operating system, because they use different chipsets. In the work of Hess et al.[28] GPS receivers running on the operating systems iOS, Android, and Windows, were compared over different devices. They learned that the accuracy of GPS measurement heavily depends on the respective smartphone. Bauer[29] did a research on the accuracy of GPS measures of Running Tracking Applications on a single device. A runner would run up and down the same track for each application, running a total of one kilometer. She showed that even among applications on the same device deviations could be found, possibly because of inconsistencies in the signal due to the mentioned influencing factors.

Research showed that smartphones could be used as an alternative to dedicated GPS devices for some purposes, but as the quality and accuracy of GPS receivers seem to be dependent on many contributing factors, such as weather, type of device, and near-obstructions, is it hard to exactly determine the quality and accuracy of GPS in smartphones. For this reason we shall look into the question of how well GPS receivers in smartphones work ourselves for the devices available for this project, by examining the accuracy and consistency of GPS in multiple devices in a situation as ideal as possible for our purpose, in order to answer the following substudy question:

- How well does GPS in mobile devices perform, and how much does it vary between different devices?

3.2 Orientation Sensors

Smartphones come packed with a variety of sensors. For this project the most important sensor is the magnetometer, which is a sensor capable of sensing the earth's magnetic field, in order to know where magnetic north is. Magnetic sensors and their applications are discussed in general by Lenz and Edelstein [30]. Different kinds of magnetic sensors are analyzed and categorized. They suggest that an accuracy of 0.1° can be reached by highly sensitive compasses. These high-accuracy compasses are a requirement for a typical aircraft system. The most common magnetic field sensors used in mobile devices[31] are based on the Hall Effect[32], which are low cost sensors, and thus widely used at the cost of lower accuracy.

While GPS receivers in smartphones have been examined in a lot of research, there exists very little data on the performance of other sensors in current mobile devices. One research that has been carried out has been done by Ruotsalainen et al. [34]. They evaluated a digital compass on a single device and found a mean error of 18.1°. More extensive research has been carried out by Hölzl et al. [35] who tested seven different mobile devices of different model types in an industrial environment. They found that the devices often could be accurate to within an error of $< 5^\circ$, but could fluctuate up to $> 60^\circ$, caused by metallic objects from manufacturing devices near the mobile device, which cause disturbances in the magnetic field, and must be taken into account for applications used in environments with metallic objects.

There are several methods to mimic an analogue compass. Methods vary in the way one or more sensors are used together in the implementation to retrieve the device's orientation. We will implement multiple methods and test them on different devices to get a better understanding of the device's possibilities and limitations, and to answer the following substudy question:

- What is the best method to implement a digital compass on a mobile device, and how much does it vary between devices?

Since our focus lies on outdoor gaming in an open field we will assume that there are no disturbances caused by metallic objects.

3.3 Location- and Orientation-aware applications

With the GPS running an application becomes location-aware, knowing the position of the user in the real world. The addition of a digital compass would make it orientation-aware, knowing which way the user is facing in the real world. This combination has not yet been widely used in applications. However, as early as 2005 Simon et al.[36] suggested a possible application for the combined technology. They suggested a model for an application that will give the user information related to locations, such as historical buildings or landmarks, in the direction the user is pointing its device. They note that the total error is a combination of the positioning error and angular error.
In 2008 they evaluated the performance of orientation-aware location-based interaction [37] by letting a user walk a variety of routes in different environments and point at designated target buildings. When the application received a correct position and orientation of the user

it would recognize the target building. They received mixed results for the routes, but as expected and according to previous work, the best results were found in a low-density urban environment, as it had the least obstructions in its environment. In this environment the success ratio was 96%. Errors were caused by positioning errors causing the line of sight according to the application to miss the building, or by a temporary compass offset. Although the results look promising, we note that buildings are rather large targets, allowing less accuracy during the pointing task whilst still hitting the target.

Mobile games with the combination of location- and orientation-aware properties are apparently not yet ready for the consumer market, but they have been explored by Hall[38] in 2011, who explores multi-player outdoor smartphone games, including the already mentioned iTron Family[19]. In an earlier research from 2006, together with Janisz [39], he studied how accurate sensors must be to support realistic simulations of shooting, and the tradeoffs that exist among the accuracies of different sensors. In their latter research from 2011 they concluded that the accuracy of smartphone device sensors did not yet meet the established requirements from their research in 2006. The even more recent work of Blum et al.[33] also looked into the sensor reliability for augmented reality applications that uses both the digital compass and GPS. They evaluated an approach to a digital compass and found the compass to have a mean error of 10°, but could have greater deviations up to 30°. The evaluated location sensor exhibited errors with means of 10-30m. From their results they also concluded that smartphone sensors require improvement for applications that use both the location- and orientation-aware properties.

From the discussed research it follows that current smartphone sensors do not seem to be accurate enough to be employed for multi-player purposes. We will tackle the question about a possible single-player game using the combination of location and orientation sensors. We will thus examine how well the combination works in such a setting in order to answer the following substudy question:

- How well does the combination of the compass and GPS feature perform?

With an implementation of a location- and orientation-aware game we will also conduct a user study. While early results show that the performance of the combination is either lacking, or seems to be sufficient, we are still interested in how the user will perceive such a game. In our user study we try to discover if any imprecision can be overlooked and a positive experience is still possible, or that it still lacks precision and will result in a negative experience, in an attempt to answer the following substudy question:

- How do people experience an implementation of an Orientation-Aware Location-Based Game?

3.4 Improvements and Shortcomings

This thesis will also be a preliminary study on this form of gaming. During our research we will make note of the shortcomings of the applied technique and attempt to discuss how they could be improved. With this we define our final substudy question as follow:

- What needs to be improved when working towards an Orientation-Aware Location-Based Game?

4 Device Hardware

Modern mobile devices come with a variety of built-in sensors that measure various environmental conditions such as motion, location, orientation, and many more. These sensors are what makes a smartphone smart and offer the great advantage of only requiring a single device instead of carrying around multiple separate dedicated devices. The sensors provide raw data which a developer can acquire and incorporate in any app to enhance the user experience. In this section we will discuss the sensors which are relevant for this research.

4.1 Location Sensors

Current mobile devices are capable of estimating the location of a user in the world. There are several strategies to estimate a user's location, which will be discussed in this section. Despite various methods with increasing precision, these estimations will always suffer from inaccuracy, depending on the method and other factors, such as the motion of the user between location updates.

4.1.1 Network Location Provider

One approach to location estimation is by using Android's Network Location Provider [42]. This approach will estimate a user's location based on nearby cell towers [43]. Since these towers include their location in their signal a mobile device can estimate its own location by measuring the angle to the cell towers and the time it takes the device's signal to reach a tower. In an area with more towers, such as a dense city, the estimation will be more accurate. It has the advantage of being faster with a low battery consumption and also working indoors. In a similar manner is it possible to acquire a location estimate using Wi-Fi. Google Streetview cars have built a database of Wi-Fi networks and locations by collecting data while driving around[54]. Using this extensive database a mobile device can estimate its location based on the locations of nearby Wi-Fi networks that are included in the database. The accuracy of such an estimation can be increased by using both the approaches simultaneously so each can cover the other's weak spots.

4.1.2 Global Position System (GPS)

The most well-known and accurate location provider is the built-in GPS receiver. This system works with satellites that will send their location to a mobile device through a message. The device is capable of determining the distance to the satellite based on the transmission time of the message and the speed of light. The device now knows it must be positioned on a sphere with the satellite as its center and a radius equal to the calculated distance. When the device receives messages from multiple satellites it can estimate its own location by intersecting the spheres. Four satellites are required to gather an accurate estimation. Three satellites are required to get 2 location estimates, and a fourth satellite to help calculate a timing and location correction and select one of the 2 remaining estimates as the location. Naturally, an increase in the number of satellites the device can connect with will increase the accuracy.

Compared to the other approaches this method is by far the most accurate. However, it does have the disadvantage of only working outside. It also demands a lot of battery consumption, and is not capable of sending location updates with a rate above 1 per second. It is possible to increase this rate, but this would require an additional GPS module. Since this thesis is about the possibilities of current mobile devices, such external modules are outside the scope of this thesis.

Current mobile devices use Assisted-GPS (A-GPS) [44]. A-GPS is GPS assisted by external sources other than satellites which greatly improves the start-up performance of the normal GPS receiver by already giving a rough estimate of the user's location.

In the Android Platform a location is given together with an estimation of its accuracy. This accuracy is expressed as the radius of 68% confidence, in other words, a circle with the given radius with the estimated location at its center describes the area of where the true locations is with a probability of 68%.

4.2 Other Sensors

Most sensors discussed in this section use the same standard 3-axis coordinate system as its frame of reference, which is relative to the device, to express their data values. The X axis is horizontal and points to the right from the device. The Y axis is vertical and points upwards from the device. Finally, the Z axis points out of the screen towards the user. Figure 1 gives a good example of the coordinate system.

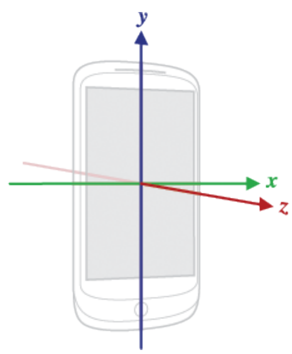
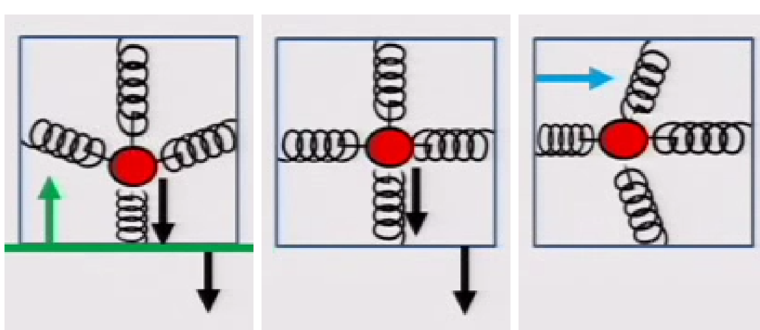


Figure 1: The coordinate system relative to a device[53].

4.2.1 Accelerometer

The accelerometer is a sensor capable of sensing motion and acceleration of the device in any direction. It allows the mobile device to respond to motions of the user. It works by using the principle of inertia. An example of how this works is visible in Figure 2. In the figure the forces at work are shown and are what is measured by the sensor. When in rest the sensor will measure the gravity (2a). In free fall there are no forces at work on the sensor resulting in a value of 0 for all directions (2b). When the device is being moved in a single direction the sensor will measure the corresponding linear acceleration (2c). A drawback of accelerometers is that there is a delay between the device decelerating and the sensor measuring the deceleration, especially when a motion is abruptly stopped.



(a) Gravity (b) Free fall (c) Linear Acceleration

Figure 2: Example of how an accelerometer works in three different states.[40]

4.2.2 Gyroscope

A gyroscope measures angular velocity, which is the rotation of its own frame of reference, or the rotation around any of its axes. It is based on the Coriolis Effect [41], which is what is perceived when a mass is moving and its frame of reference is rotating. Moving or rotating objects tend to keep moving or rotating in the same way. When an object is no longer allowed to rotate in the same way it tries to push against the change. This effect is measurable as a force on the mass. This force can be sensed by a gyroscope to measure the angular velocity. The gyroscope also has a drawback. Over time drift in the data is picked up, caused by an integration of the sensor data, as white noise of the reading is accumulated by the integration.

4.2.3 Magnetometer

The magnetometer is the sensor that monitors changes in the earth's magnetic field. It is useful for getting a direction to the magnetic north. The most common sensors in mobile devices are based on the Hall Effect. These magnetometers measure current in a wire. The Hall Effect is what deflects the current in a wire when a magnetic field is present. The amount of deflection can then be measured. Its biggest drawback is that it is also very prone to disturbances in the magnetic field, as external factors can distort the field. External factors include metallic objects, laptops, electronic cables, and even other components included in the smartphone.

4.3 Approach to a Compass

Mobile devices do not come with a built-in compass feature, but instead include sensors capable of mimicking a compass. This allows developers multiple methods to implement a compass function by addressing one or more of the sensors discussed in Section 4.2. Since multiple methods exists and no direct best method is available we looked into a few approaches to implement a compass. The implementations will be discussed in the following sections. The implementations will be compared in the experiment in Section 5.1.1.

When developing an application where navigation is a crucial part, magnetic declination must be taken into account. An implemented digital compass works by measuring the earth's magnetic field. This means that the compass will point to the magnetic north. However, in normal navigation we work with true north, which is the direction along a meridian towards the geographic north pole. The angle between the direction to the magnetic north and the direction to true north is called the magnetic declination and depends on the user's position on the earth's surface. To get the declination we must know the user's location. When this is known the Android platform allows us to retrieve the declination at that location.

4.3.1 Simple Compass

The first approach is the easiest implementation, but unfortunately also a deprecated method. It uses a sensor provided by the Android platform. This sensor has been deprecated in newer Android Version, but is still usable in recent devices. We will also test this implementation since our available devices are still capable of using this approach. The approach invokes the TYPE_ORIENTATION sensor [45] in Android, which derives its data directly from the accelerometer and magnetometer.

4.3.2 Magneto- and Accelerometer Compass

With the previous approach actually being deprecated we looked at an implementation that invokes the magnetometer and accelerometer separately. The use of the magnetometer speaks for itself, since it is necessary to measure the earth's magnetic field. Unfortunately the magnetometer alone is not sufficient unless you align the frame of reference of the device with the frame of reference of the earth. This is, of course, impossible when it should be used in a game where the user is required to move the device. The addition of the accelerometer is necessary as it is not only used for measuring acceleration, but also to measure gravity. Without this, the device would not know where *"down"* is, which is necessary to determine the direction of the horizontal plane. The code for the implementation of this approach was based on a code sample of Samsung [47].

4.3.3 Sensor Fusion

This approach also includes the gyroscope in conjunction with the magnetometer and the accelerometer. The combination of the accelerometer and magnetometer determine the device's orientation in relation to a global coordinate system. Unfortunately both sensors are prone to noise; the magnetometer in particular. To reduce the amount of noise in the data from the magnetometer and accelerometer, a low-pass filter can be added. However, this causes a visible delay in the update time of the compass. The gyroscope is capable of quickly responding to a user's motion. The delay by the two sensors can be removed by the data from the gyroscope. The gyroscope however, suffers from drift which causes small errors to be accumulated in a long term measurement. By adding a high-pass filter to the data the drift can be eliminated when missing data is replaced by data from the low-pass filtered information from the other two sensors. This configuration is called a complementary filter [48]. The entire approach to this compass is shown in Figure 3. The code used for this implementation was based on the code from the thesis of P. Lawitzki [46].

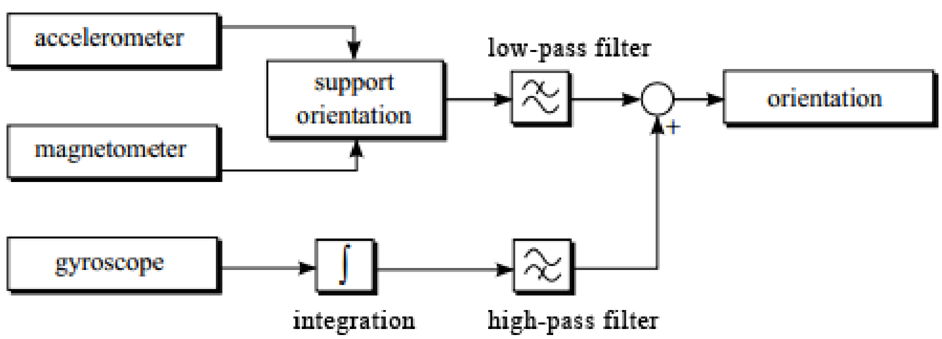


Figure 3: Sensor data fusion with a complementary filter [46]

5 First Experiment: Hardware test

As discussed, current mobile devices each have their own hardware depending on the manufacturer. Even though the devices share the same software to read the input from the sensors, the readings might differ greatly in their values, especially since each sensor is prone to noise. In order to know what we can expect from the hardware we want to know how well both the GPS receiver and the implemented compass methods perform individually and compared between different devices, and secondly how well the combination of GPS and compass performs, before we conduct a final user study with the technology. The experiments from this section are therefore designed, implemented and performed to test these components.

5.1 Experiment Design

5.1.1 Compass Test

Mobile devices do not come delivered with a standard compass function for developers to use. They do provide the necessary sensors to implement a compass feature ourselves. Therefore, several methods to mimic an analogue compass are possible, as discussed in Section 4.3. To learn which method performs best, and how well they perform on different devices, we compare each approach with an analogue compass. We will thus compare the measured magnetic north by each implementation on the mobile devices with the magnetic north according to an analogue compass, which we assume to have the correct value.

For each of the cardinal directions we align multiple devices with an analogue compass. By gathering the discrepancy between a series of the device's readings and the direction of the compass we can estimate the inaccuracy of each method on each device. We gather multiple readings with a pace of once per second of the implemented compass and average them, since unlike the analogue compass whose direction should remain static while being immobile, the implemented compass is expected to oscillate a little bit due to the noise in its sensors, causing a non-constant error. Averaging them should give us a better estimate. The pace is not too fast because a too fast pace could result in readings too close together. An example of the experiment setup is shown in Figure 4. The steps of this experiment are as follows:

- Align analogue compass with a cardinal direction.
- Align device with the compass.
- Read 10 implemented compass readings with a rate of once per second.
- Average the discrepancy of the readings with the current cardinal direction.

Repeat the steps for each cardinal direction, each device, and each implemented compass.

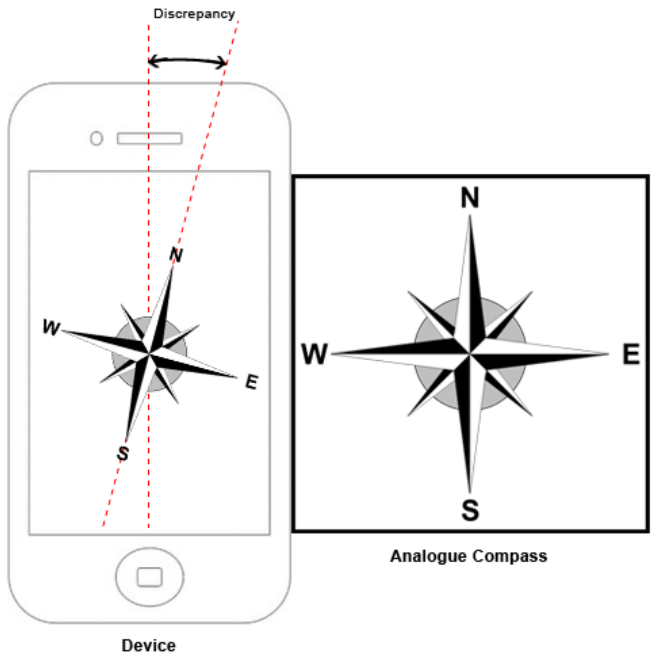


Figure 4: The setup of the compass experiment. The device is aligned with an analogue compass, which is in this case pointing north. The discrepancy is the angle between the north according to the device and actual north as indicated by the analogue compass.

5.1.2 GPS Test

Current day mobile devices provide several strategies to acquire a user's location. These strategies have been discussed in Section 4.1, but by far the most accurate provider is the GPS receiver. Normal GPS receivers have a standard accuracy of at least 15 meters, which with augmentation can be decreased to 3 meters [49]. Since manufacturers of mobile devices have to make a tradeoff between performance and production cost, we expect GPS receivers incorporated in mobile devices to suffer from more inaccurate and imprecise readings, resulting in an expected inconsistency when collecting the GPS coordinates of the same location in the world at two different times.

To get a sense of how imprecise these readings are, we collect the GPS readings of a device located on a specific location. The device will give us an estimation of the accuracy of the reading, and for this experiment we will attempt to select most accurate reading as possible, by giving the device time to acquire the best estimate on each location. Between the readings we will move the device away from the location, only to return to get the next GPS reading. We then calculate the average distance between all the points to express the inconsistency between the readings in meters. The locations are chosen in an open area, with as few as possible obstacles hindering the signal, because our research focuses on outdoor applications, for example on fields. The steps are summarized as follows:

- Pick a distinctive location with an unobstructed sky.
- Get an as accurate as possible GPS reading of the location.
- Move device away from location.
- Return to location and gather a new and an as accurate as possible GPS reading.

  Repeat these steps 5 times and average the distance between each reading.

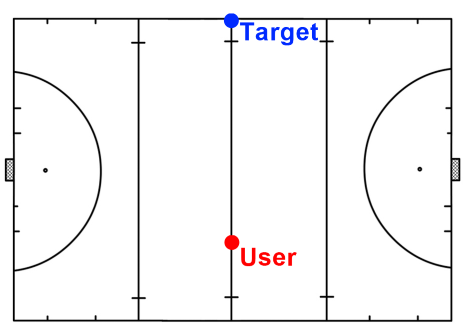
  Repeat for multiple locations.

  Repeat for each device.

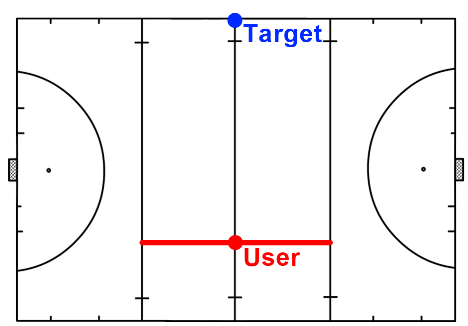
5.1.3 GPS & Compass Test

In preparation for the user study we will first look into an experiment where our 2 prime features work together, namely the implemented compass and the GPS receiver. When both the GPS and compass feature are combined the mobile device will be aware of both a player's location and orientation in the real world, opening up a range of possibilities. Unfortunately each feature may come with noise in its data resulting in unwanted inaccuracies. When combining the components the problems of the inaccuracy may amplify each other. In a type of shooter game the locations of players or targets are equally important as the direction they are aiming at. When any of these factors contain an error it will diminish the player experience. Until now we have also limited ourselves to testing the sensors while keeping the devices static. We can not expect this to occur when players will use the device, therefore we will also look into situations where the players and targets are in motion.

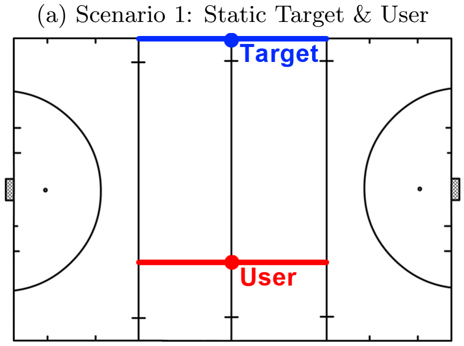
To test the combination we conduct an experiment where both the components work together. We use the compass to read the user's orientation, and use it to enable the user to aim at his environment. Meanwhile, the GPS receiver will track the user's location, and place the user on a virtual world. We test the compass by aiming at targets. These targets are given a location that corresponds with a location in the actual world. We do this by requesting the coordinates from the GPS receiver for the location in the real world. The target will now have this location translated to a location in the virtual world. We then aim at the target and save the inconsistency between the direction to the target and the aiming direction. We carry this out for 3 different scenarios with an increase in motion of the user and targets for each scenario. In the first scenario both the user and the target are static, as represented in Figure 5a. In the second scenario the user moves in a line parallel to the target, as can be seen in Figure 5b. In these scenarios the user is aware of where the target is supposed to be, as its location should match a recognizable location in the actual world. We expect that the increase in dynamic between the first and second scenario will decrease the accuracy. The user will aim at the real world location where the target is supposed to be located. The error is dependent on the accuracy of the initially acquired target's location, the current received player's location, the accuracy of the compass, and the player's own aim. The highest error is expected in the second scenario because of the increased motion by the player.



(a) Scenario 1: Static Target & User



(b) Scenario 2: Moving user & Static Target



(c) Scenario 3: Moving user & Moving Target

Figure 5: A representation of each scenario.

In Figure 5c it can be seen that both the user and the target move. They do this in opposite direction over two parallel lines. The target will now also move in the virtual world. It still has a counterpart location in the real world, but the user no longer exactly knows where this should be. In this scenario the user will rely more on where the application is telling him where the target is located, making the target's exact location in the actual world less relevant. What will be measured in this scenario is how accurate a moving user can shoot at a moving target while relying on feedback from the virtual world.
The steps to be carried out for this experiment are as follow:

- Acquire GPS locations of recognizable locations in the actual world according to the current scenario.
- Position player according to the current scenario.
- Move according to the current scenario.
- Aim and shoot 5 times with a frequency of once per second on the target.

  Repeat experiment per scenario and average results.

In order to measure the accuracy in each scenario we measure the angle between the line from the player to the target and the line in the direction the player is aiming at when shooting, as seen in Figure 6. The discrepancy between the lines for each shot is averaged to get an insight in the performance of the implemented compass method for each scenario when used by a player.

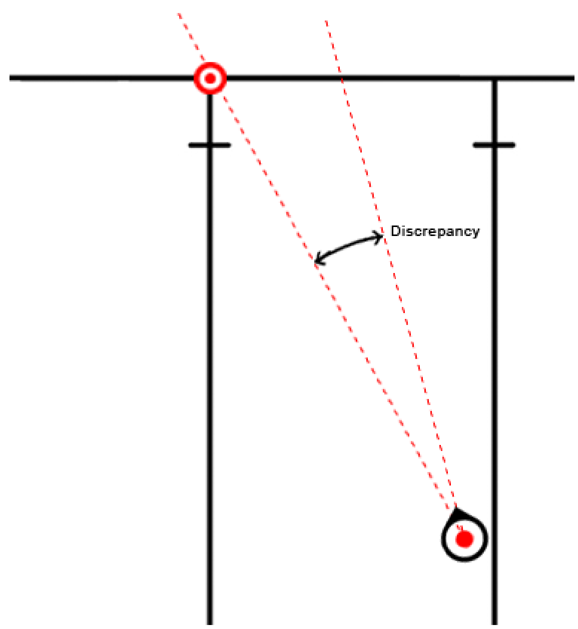


Figure 6: Image showing how the accuracy is measured during the experiment.

5.2 Results

The experiments from Section 5.1 have been carried out with one or more mobile devices running Android. Depending on the experiment, the devices used were one or more of the following:

- Samsung **Galaxy S2** Plus
- Samsung **Galaxy S3** Mini
- Samsung **Galaxy Tab** 1
- **Nexus** Tablet

5.2.1 Compass Test

We carried out the compass experiment from Section 5.1.1, where we tested the 3 implemented methods from Section 4.3 on all four available devices. The average discrepancy for each device is shown in Figure 7. Table 1 is more extensive and contains the average discrepancy between each cardinal direction and the 10 readings according to each implemented method.

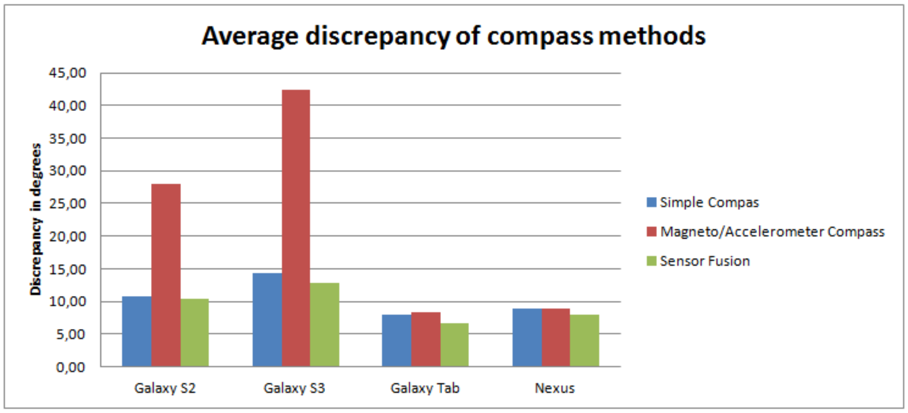


Figure 7: The average discrepancy for each compass method on each device.

Method	Direction	Device			
		Galaxy S2	**Galaxy S3**	**Galaxy Tab**	**Nexus**
Simple Compass	North	9.94	0.38	3.41	14.89
	East	18.70	27.35	15.51	3.60
	South	3.38	2.88	1.18	14.67
	West	11.46	26.55	11.80	2.19
	Avg:	10.87	14.29	7.98	8.84
Magneto / Accelero-meter Compass	North	35.69	36.42	1.57	15.91
	East	46.68	70.64	14.58	1.61
	South	18.50	46.46	1.09	15.99
	West	11.41	16.36	15.77	1.94
	Avg:	28.07	42.47	8.25	8.86
Sensor Fusion	North	8.84	0.18	1.98	13.09
	East	18.63	25.11	14.92	1.53
	South	1.45	2.89	0.41	14.97
	West	12.54	23.41	9.55	2.04
	Avg:	10.37	12.90	6.71	7.91

Table 1: This table shows the average discrepancy in degrees between each cardinal direction and each implemented compass method.

From Figure 7 we learn that the average accuracy of the compass may differ greatly between devices, and that the tablets performed notably better than the mobile phones, probably due to better hardware. When looking at the more extensive Table 1 we see that there is a widespread in the accuracy between methods and devices, ranging from a very accurate 0.18° to a dramatic discrepancy of 70.64° between a method's reading and the actual direction, and we see that it can even deviate between the cardinal directions. From both the figure and the table it is clear that the implemented Magneto- and Accelerometer performed horribly. During testing we noted that this was also the least consistent method as it quickly skipped between different values contributing to a worse performance. That the Simple Compass does not suffer from the same inaccuracy despite of also being based on a magneto- and accelerometer is probably due to that the Android platform applies a filter to the data from the deprecated sensor. The Magneto- and Accelerometer Compass does not apply such a filter resulting in a lot of unwanted noise and unpredictable deviations.

The best implementation is the Sensor Fusion approach, which could be expected as it uses more sensors that can correct each others faulty data when combined. The Sensor Fusion does not outperform the Simple Compass with a large margin, but the advantage of the Sensor Fusion is that it uses the gyroscope which contribute to a better accuracy when the device is in motion, because it allows the compass to respond quickly on a motion by the user. This advantage was not present during this test, since the devices remained motionless during testing. Sensor Fusion will have this advantage during the user study, and thus will be the user method during the remaining experiments.

We note that there is not a very notable difference between the two tablets, with the Samsung Galaxy Tab 1 performing slightly better. This is also the device that will be used during the user study in Section 6. The Sensor Fusion approach will be used as the compass in the experiments from Sections 5.1.3 and 6.

5.2.2 GPS Test

In the experiment from Section 5.1.2 we measured the average discrepancy between multiple readings of the same location in the actual world. The experiment has been carried out with all four available devices. Table 2 shows this average discrepancy for two locations in meters, together with the average accuracy of the received locations.

	Device			
	Galaxy S2	**Galaxy S3**	**Galaxy Tab**	**Nexus**
	Avg Disc	Avg Disc	Avg Disc	Avg Disc
Location 1:	5.29	9.63	3.02	8.04
Location 2:	2.11	5.93	2.23	7.75
Average:	7.78	3.70	2.62	7.90

Table 2: This table shows the average discrepancy in meters between multiple received GPS locations of the same locations.

Table 2 gives us a depiction of how well the GPS receiver of multiple mobile devices performs in terms of precision. Per device and location the average difference between each received location is given in meters.

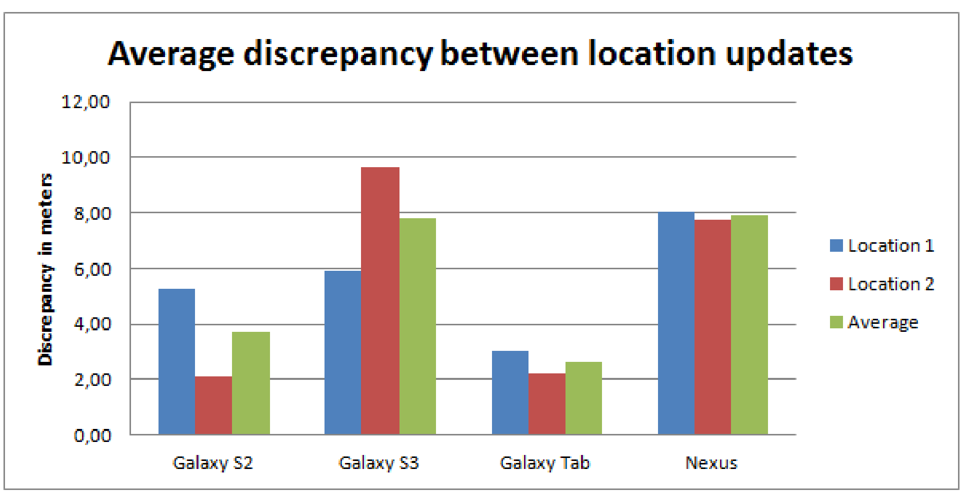


Figure 8: The average discrepancy in meters between received location updates of the same location.

From Table 2 and Figure 8 we learn that the devices all perform within an error range of 10 meters, and can be as precise up to 2.11 meters. The accuracy radius is omitted from the table, but we also saw that the average accuracy confidence radius was within a range of [4..10] for all devices, meaning that in the worst case a device is 68% confident that the exact location is within a range of 10 meters. A better accuracy of the location estimates would also have a positive effect on the precision of the estimates.

From Figure 8 it is clear that the best results have been gathered with the Samsung Galaxy Tab, with only an average discrepancy of 2.62 meters. This shows that it is possible to get rather precise locations from the GPS receiver. However, in a game where the locations of multiple players are being tracked, imprecision within the range from this experiment are still too large for practical purposes.

5.2.3 GPS & Compass Test

In the experiment from Section 5.1.3 we tested how well the combination of GPS and compass worked when applied simultaneously. The experiment has been carried out with the Sensor Fusion approach to a compass. The features were tested over 3 scenarios with increasing motion by the user and targets. In the scenarios the user's location in the real world was translated to a virtual world, and contained a target that had a location in the virtual world based on a location in the real world. Using the compass the user had to aim at the target.

We make a distinction between the first two scenarios and the final scenario. In the first two scenarios the user is aware of where the target is supposed to be since its location in the real world is known and static, and the final scenario in which the target moves and its location is no longer exactly known and thus the user must rely on the information shown about the virtual world on the device. In the latter scenario the actual position of the target in the real world becomes less relevant as its location can be considered relative to the user. In the first two scenarios we consider its location as absolute. When the location is absolute the imprecision is expected to be greater as there are more contributing factors, namely the tracked location of the user, the calibrated location of the target, and the compass. With a relative position the compass feature is the most important. However, the user should still have a picture of the vicinity of where the target should be. When this condition is not met it could diminish the user experience.

Table 3 shows the average discrepancy between the aiming direction of the user and the direction to the target for each scenario and 3 different devices.

	Device			
Scenario	Galaxy S2	Galaxy Tab	Nexus	Average
1: Static Target & User	30.82	12.76	17.80	20.46
2: Static Target & Moving User	36.29	37.52	23.36	32.39
3: Moving Target & User	10.76	11.30	9.55	10.53

Table 3: This table shows the average discrepancy between the aiming direction of the user and the actual direction from the user to the target in degrees.

In this table we see that for the the first two scenarios the target is missed by a large angle. As expected the second scenario yields the worst results, since we expected to have a greater inaccuracy while moving. To get an accurate shot during the first two scenarios the compass must be very accurate while the current location of the user also must be very accurate as well as the calibrated location of the target. As all these factors come with their own inaccuracies, the combined product delivers a very inaccurate result not suitable for practical purposes, even when a small margin of inaccuracy is allowed. Scenario 1 and 2 indicate that a multi-player game is not yet very feasible.

The third scenario where both the target and the user were moving shows better results. In this scenario the user can envision where the target is approximately located, but relies more on feedback about its location on the mobile device. Therefore, the results are mostly determined by the implemented compass. The target is still missed by an average angle of 10.53 degrees. When we consider the shot as a cone, instead of a line, we enter an allowed margin of error into the results. A cone of 22 degrees would count shots that missed by an angle of ≤ 11 degrees as a hit, meaning that with such a cone roughly half of the shots fired during the experiment would have hit the target.

An important contributing factor that has not been included in the results is the error in the actual aim of the user as this was unmeasurable, but we assume that the user had a good aim during the experiment. To ensure this the user was able to prepare himself to get a good aim for the first shot which marked the start of the test. The angle from the results by which the targets have been missed are therefore based on a game-like situation, instead of a situation where the aim was exactly correct.

6 Final Experiment: User study

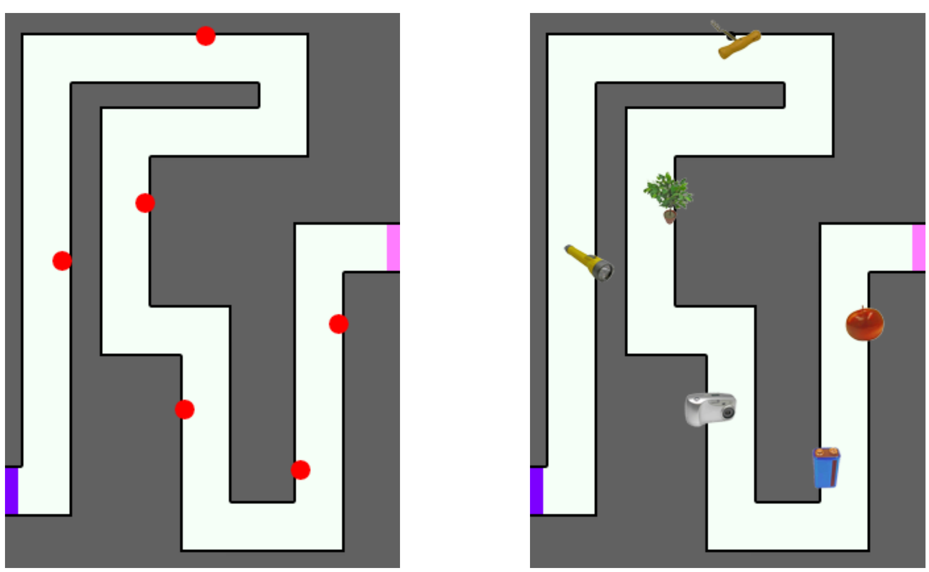
To actually test how well the envisioned type of shooter game might work that incorporates both the compass and GPS, an experiment which uses both is conducted and grounded to a user study, in order to also learn how well users respond to the technique. For the study a number of test subjects will act as our players. This experiment is combined with the research of A. Faber [51], who conducts navigation research about how people navigate in a virtual world compared to their normal navigation abilities. This collaboration shaped the final user test and explains why some choices in its design have been made.

6.1 Experiment Design

An application was designed and implemented with features of a shooter game. The goal of the game is to navigate over a virtual map, and shoot at targets that appear at predetermined locations. The compass function of the device is used to aim at the targets and the player's location on the map is controlled by the GPS receiver. By walking in the real world the player moves over the virtual map while the player can aim by rotating the device in the horizontal plane. By touching the screen the player can shoot in his current direction. The player will earn points by hitting each target. The score the player will receive depends on the response time, the accuracy, and the number of necessary shots to hit the target. The components are evaluated based on how well the tasks of navigating over the map and aiming at the targets have been carried out, according to the data and according to the test subjects.

6.1.1 Virtual Map

The virtual map contains a route which is based on an actual route from the research of Faber. As location for the experiment a hockey field was chosen. This has the advantage of a secluded area with known dimensions and little obstacles to hinder the GPS signal. We let the corners of the virtual map match the corners of the hockey field. This contains the player route to within the boundaries of the hockey field. Figure 9a shows the route the players should walk, together with the locations of the targets.



(a) The virtual map with the locations of the targets.

(b) The virtual map with the objects on the target locations.

Figure 9: Images of the virtual map with the targets.

6.1.2 Game Setup

The player will only see a small portion of the virtual map on the screen of the device. This way the player only has information about a small area around him and does not know the route in advance. An example of what the player sees on the screen is depicted in Figure 10a. The player's location on the map is shown as a dot with a pointer indicating the player's aiming direction. The aiming direction is decided by the implemented Sensor Fusion Compass. However, the direction of this pointer on the screen remains static, as opposed to the virtual world which rotates with respect to the player.
While a player walks along the route targets will appear. As part of the research of Faber the targets are actually common objects, because the users are later asked to recall which objects they have encountered. Figure 9b shows where and what kind of objects the players will encounter. The objects the players will encounter are an apple, battery, camera, plant, screwdriver, and a flashlight.
A shot is defined as a cone starting out from the player. The cone has an angle of 18 degrees. This means that each shot with an accuracy of $\leq 9^\circ$ results in a hit. The choice for the size of the cone is based on the results from Section 5.2.3, where a cone with an angle of 22° would be sufficient. We chose a slightly smaller cone as the targets will remain static and players are allowed multiple attempts at hitting a target, although at the cost of a penalty.
The score for the landmarks is calculated by Equation 1. Equation 2 is the same equation, but with more details.

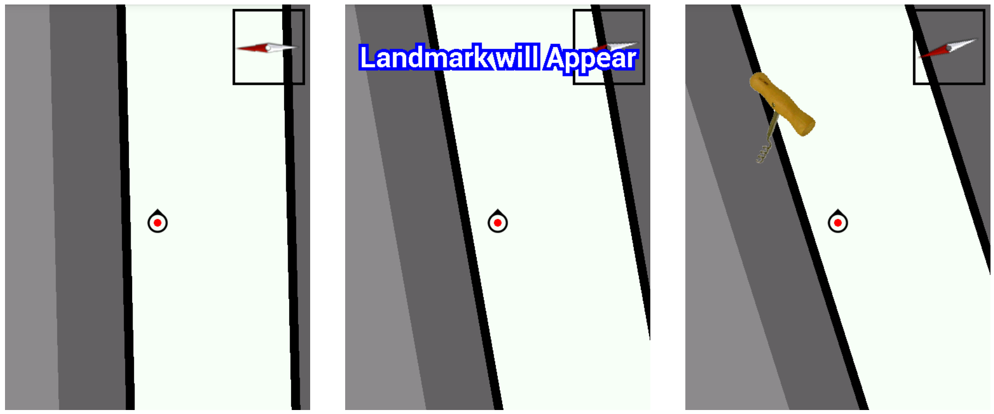
$$\sum_{i=1}^{6}\left(\frac{InitialScore_i + AccuracyBonus_i + TimeBonus_i}{NumberOfAttempts_i}\right) \tag{1}$$

$$\sum_{i=1}^{6}\left(\frac{500 + ((9 - a_{x_i}) * 100) + (5000 - Max(t_{x_i} - t_i, 0)}{x_i}\right) \tag{2}$$

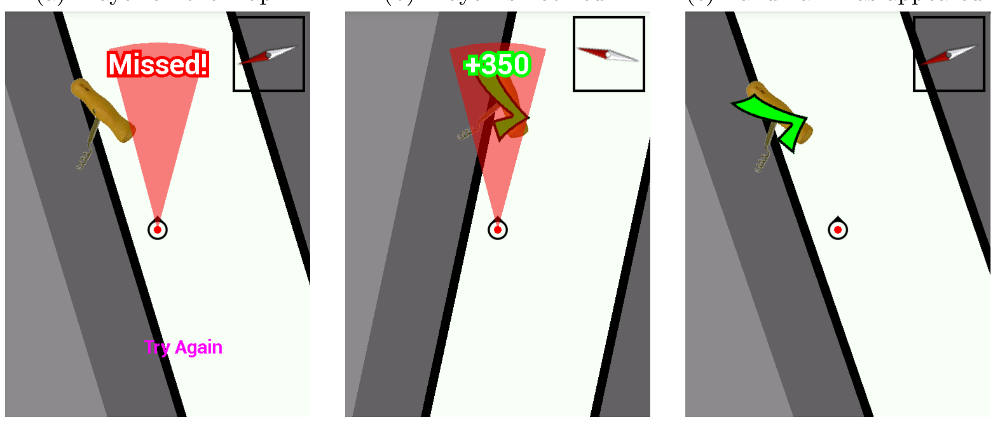
Here i corresponds with the active landmark, x_i is the number of the first shot that has hit landmark i and thus the number of shots that were necessary to hit landmark i, a_{x_i} is the accuracy of shot x_i, t_i is the time landmark i appeared in nanoseconds, and t_{x_i} is the time the landmark was hit by shot x_i.
This equation was conceived in this form to reward the player for his accuracy and his speed, with a penalty when more shots are necessary. The initial score was added to avoid that players would receive a score of near zero. Negative scores are not possible, not even because of the part $9 - a_{x_i}$, since a_{x_i} is always smaller than or equal to 9° as it is the accuracy of the first shot that hit.

6.1.3 Game Progress

The player is asked to start in the pink area of the map. When the player enters this area the experiment starts and the player is asked to begin walking down the path. When the player approaches a target a message will appear to notify the player. When the player is close enough the target will actually appear and the player must aim and shoot at the target. When the player misses it will be notified and is asked to try again. As soon as the player hits the target he will be notified about his score and must continue along the route until the next landmark appears. Eventually the player will enter the purple area, which marks the end of the route. The experiment is automatically stopped and the results are stored. An example of a player encountering a landmark is visible in Figure 10.



(a) Player on the map. (b) Player is notified. (c) Landmark has appeared.



(d) Player missed target. (e) Player hit target. (f) Player can continue.

Figure 10: A sequence of a player encountering and interacting with a target. The white area is the path. Black indicates the path's boundary. Gray indicates the area outside of the path.

6.1.4 Training Session

Before the actual study will be performed, the test subjects will be made familiar with the application by carrying out a simplified version of the experiment. It will let subjects walk over a shorter and less complicated route containing only two landmarks and one corner. The training route is shown in Figure 11. Instructions about how to control the application will be given beforehand. While the subject walks along the training route one of the researchers will walk along to provide additional comments or answer the subject's questions to make sure the subject will have a full understanding of how the application operates before carrying out the actual experiment. After completing the route and making sure the subject is able to carry out the experiment, the final instructions will be given.

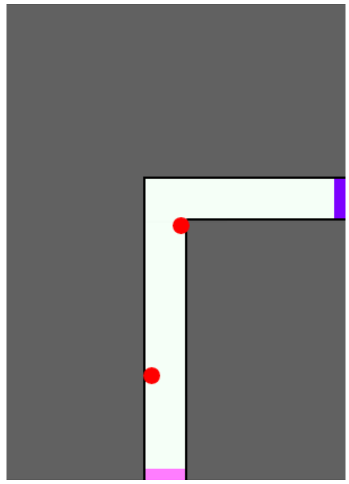


Figure 11: The virtual map with the training route and the locations of the two targets.

6.1.5 Questionnaire

To not only gather data from the application, but also from the subjects, the test subjects will be given a questionnaire after they complete the test. The questionnaire aims to determine two things, the first being how the subject experienced the application. We want to know how the subject experienced the working of the different sensors and how much their experience matched the measurable working of the application. The second goal of the questionnaire is to determine what kind of user of mobile devices the subject is, in order to be able to draw conclusions between their results and the type of mobile user they are.

The questionnaire consists of statements where the subjects can answer on a Likert scale [52] in the range of [1..7] of how much they agree with the statement, where 1 means the subject completely disagrees with the statement, and 7 means the subject completely agrees with the statement. This should provide us with a wide enough range to draw conclusions from the experience of the subjects.

6.2 Results

The results in this section are gathered from the experiment in Section 6. We collected data from a questionnaire completed by the test subjects and data from the application while the subjects carried out the experiment.

6.2.1 Users

The experiment was carried out by a total of 20 test subjects, all students, from a variety of study backgrounds. All of the 20 subjects answered a questionnaire. We gathered application data of 16 test subjects, because the application failed to store the data of 4 subjects. There was a slight difference in the number of male versus female participants, as shown in Figure 12. Since the use of mobile devices has spread equally across both genders, this difference is not an issue.[50].

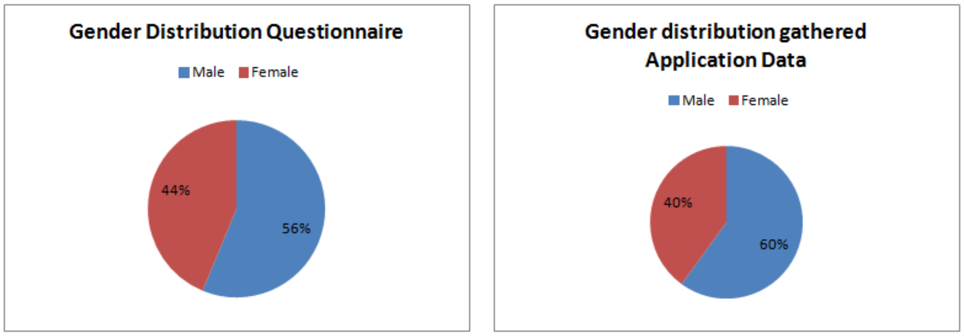


Figure 12: The gender distribution for the questionnaire and the gathered data.

How often test subjects played video games differed greatly, with a large group that hardly played any video games and a large group that played video games very often, with a small distribution between the remaining subjects. When asked how often the subjects played games on their mobile devices the distribution between their answers seemed less diverse, with a large group barely playing any games and a slight distribution between more regular players of mobile games. Both distributions are shown in Figure 13.

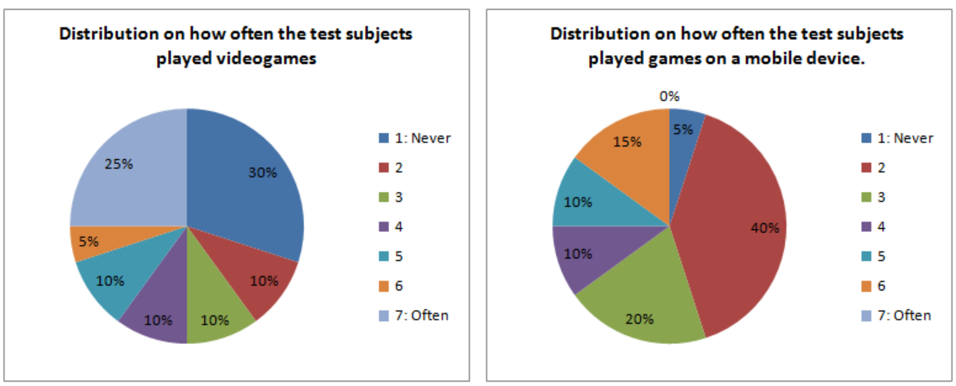
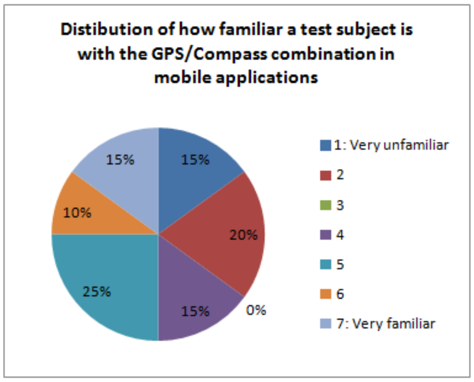


Figure 13: Graphs showing how familiar our test subjects are with video and mobile games in a range of [1..7], where 1 means the subject never plays any games, and 7 means the subject plays games very often.

We were also interested in how familiar the subjects where with the combination of the GPS and Compass features of mobile devices. Figure 14 shows this distribution about the familiarity of the combination in both mobile applications and mobile games. In mobile applications there was a very diverse distribution between how acquainted the subjects were with the combination in mobile application, but when asked about the combination in mobile games only a few people seemed to be familiar with the technique, showing that it is still rather new, especially in mobile games.



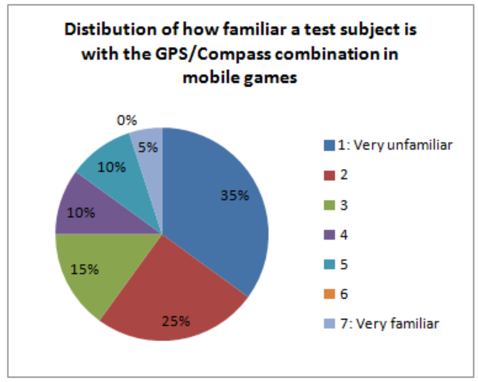


Figure 14: Graphs showing how familiar our test subjects are with the used technology in mobile applications and mobile games in a range of [1..7], where 1 means the subject is very unfamiliar with the combination, and 7 means the subject is very familiar with it.

This demonstrates that we have used a diverse user group for the user study and should allow us to draw conclusions when comparing the application results with the background of the users according to the questionnaire.

6.2.2 Results

With the data gathered from both the application and questionnaire we can look into the results. A few of the findings indicate the following:

- People were enthusiastic about the application and its technology.
  - Subjects indicated to enjoy the test and the application.
  - Subjects rated the prospect about the technology as promising.
  - Subjects rated the implemented compass as good.
  - Subjects rated the GPS feature above average.
- Data from the application showed promising results.
  - Subjects had little trouble with staying on the path.
  - The average accuracy of shots was within a very acceptable range.

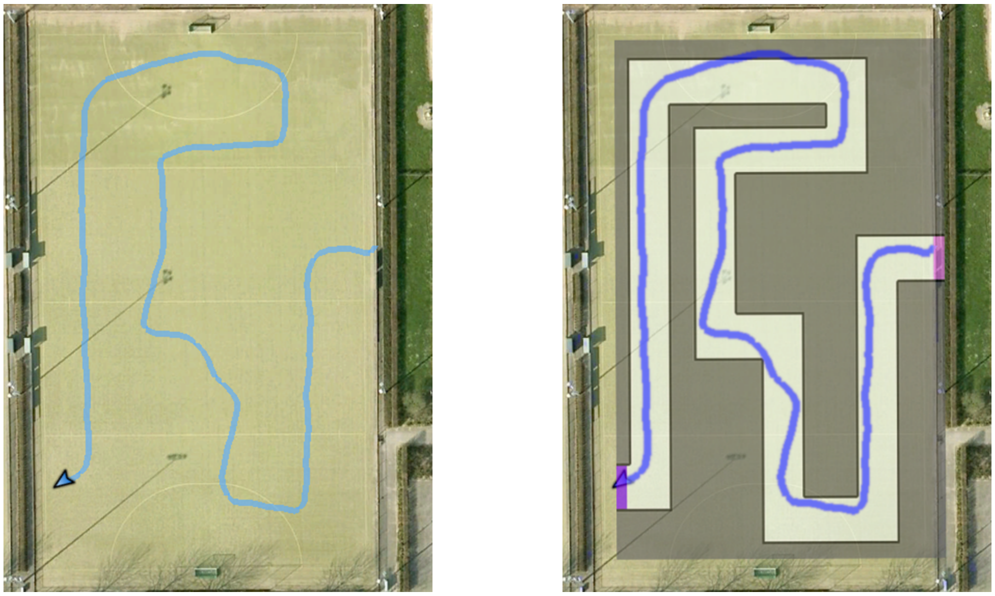
When we look into the answers the subjects gave in the questionnaire, we see that they gave very positive feedback. On the scale of 1 to 7 they responded with an average 6.35 on how much they liked to play the “game”. They also expected the technology to be used in the future with an average of 6.10. There was no visible difference between the answers from more advanced gamers with the less experienced people. From this we can draw the conclusion that even though the technology may not be very advanced yet, our subjects and probably more people are open to the idea and will probably enjoy games with these features. More statements from the questionnaire and the average responses by the subjects are listed in Table 4.

Statement	Avg Score
1: I can imagine that this technique will be applied in future games	6.10
2: I enjoyed playing the “game”	6.35
3: It was hard not to diverge from the path	3.60
4: It was hard to aim at the targets	3.55
5: The feedback about shooting matched my own experience	4.90
6: The direction I walked in matched with what I saw on the device	4.35
7: How I moved over the virtual map matched my route in the RW	4.85
8: The VW rotated in agreement with my own sense of direction	5.15
9: The VW rotated in a logical manner	5.50

Table 4: Statements from the questionnaire and the averaged responses of the subjects on the questionnaire in the range [1..7].

Before we look into the application data we can look at how the subjects experienced carrying out the tasks from the experiment by examining their answers on the questionnaire. How the players experienced the combination of the compass and GPS is mostly defined by their answers on statement 6 and 7, where they rated the translation of their movements between the virtual and the real world. Their path and walking direction in the real world should agree with what they see on the virtual map on the screen, as it depends on both the GPS for accurate location updates and compass for the rotation of the virtual world. The subjects responded with a 4.35 and 4.85 and thus indicated that this part works rather well, although not perfectly. However, they did not indicate that it was easy to stay on the path, but also did not suggest that is was hard with an average score of 3.6 on statement 3.
According to the subjects the virtual world rotated in a logical manner and matched their own sense of direction with an average score of 5.50 and 5.15 respectively. As this is mainly dependent on the implemented compass, it indicates that subjects agreed mostly with its performance. However, the difficulty of shooting was rated neither low nor high, but scored an averaged 3.55, but according to the averaged 4.9 the players did agree with the feedback about their shots.

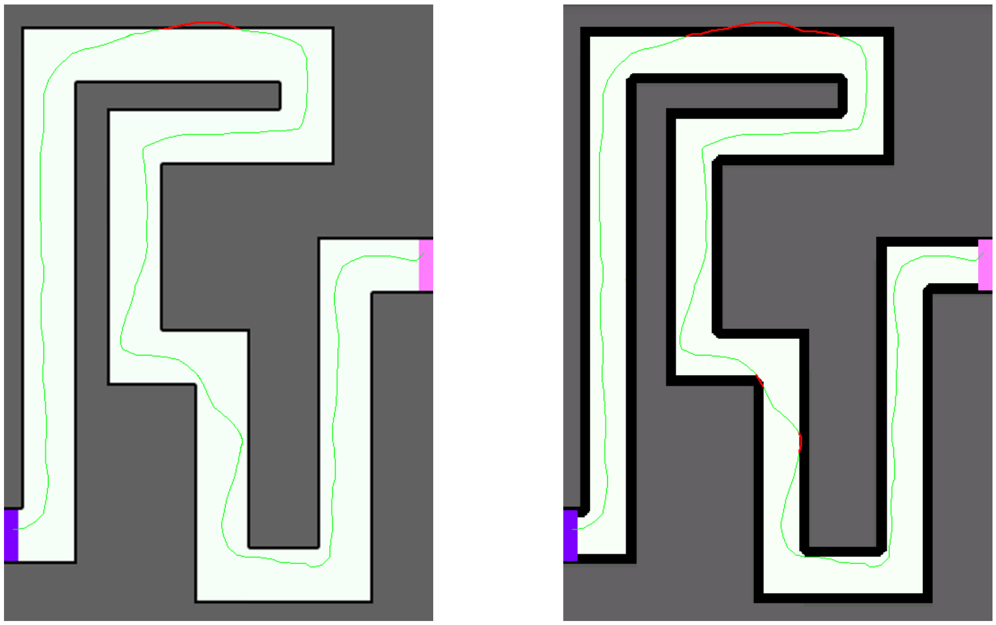
From the data of the application we can collect hard facts. We are interested in how well the features worked in our scenario. This means that we need to look at results from the GPS and compass features individually. GPS was used for tracking the player’s location and placing it on the virtual map. An objective of the players was to follow and stay on the path. The application tracked and stored the entire path of each player, which we can visualise by placing the data on a Google Map. In Figure 15a the path of one of the players is visible. The route from the experiment is clearly reflected in this image, but becomes more evident when we also place the map from the experiment over the image, as seen in Figure 15b. This already shows that the application works sufficiently well to let subjects traverse the intended route. We do see that the corners of the virtual map, indicated by the dark rectangle, do not exactly match the corners of the hockey field. This is due to slightly inaccurately received locations when calibrating them.



(a) A subject's path. (b) Path together with the map.

Figure 15: Images of the virtual map with the targets.

These first results are promising, as one of the tasks was for the players to follow and stay on the path. This requires enough feedback to the player about his current location and a sufficient working location receiver. A way to measure its effectiveness is by looking at how often the players diverged from the path. When measuring this for each subject we calculated that they only collided with the walls on an average of 2.33% of the entire route. Figure 16a shows the trajectory of a player with only a small part that was off track, which has been marked red. When also including parts of the path that were close to the walls into this calculation, because players should try to stick to the centre of the path, we calculated an average of 11.51% of the entire route as too far off track, leaving still 88.49% as clearly on the path. Figure 16b shows the same subject's trajectory on a map with a narrower path. This trajectory is also exactly how the subject saw himself move in the virtual world.



(a) The normal path. (b) A smaller path.

Figure 16: Trajectory of a subject on the map from the experiment. Parts of the route that were off track are marked in red.

From this we can conclude that the players had little trouble completing the task of following and staying on the path. Despite these results, some subjects still indicated on the questionnaire that they found it difficult to stay on the path. Strangely enough we did not find a correlation between these answers and how much they actually got off track. As seen in the correlation matrix in Figure 17, the found correlation was only 0.07, suggesting that subjects had trouble estimating their performance of this task. Another correlation we can extract from the matrix is that the walking speed of a player increases his likelihood to get off track, with a found correlation of -0.76. This does suggest that when increasing speed, the performance of the GPS tracker decreases, which can be an issue if we envision games where players have to move with speed. The accuracy of the compass, however, did not seem to suffer from the speed of the subjects with a correlation of only -0.07.
As additional comment some subjects mentioned that the update time between locations caused them to go off track or miss targets. This delay is probably also responsible for faster players diverging more from the path. Since current GPS receivers in mobile devices only update with a rate of once per second, this shall remain an issue until better GPS receivers are integrated in mobile devices.

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Gender	1,00														
2	Duration	-0,64	1,00													
3	Score	-0,19	-0,22	1,00												
4	Off Track	0,42	-0,76	0,05	1,00											
5	Avg Accuracy	0,24	-0,07	-0,61	0,14	1,00										
6	# Shots	0,50	0,03	-0,79	-0,09	0,74	1,00									
7	Virtual object in RW understanding	-0,13	-0,17	0,58	0,15	-0,61	-0,51	1,00								
8	Aiming Difficulty	0,03	-0,08	-0,33	0,02	0,58	0,36	-0,52	1,00							
9	Agreed with feedback about shooting	-0,19	0,31	0,37	-0,48	-0,52	-0,28	0,28	-0,50	1,00						
10	Walking direction matched with the virtual path	-0,16	0,19	0,11	-0,26	0,01	-0,02	0,25	0,31	-0,23	1,00					
11	Movement virtual map matched path RW	-0,22	0,32	0,09	-0,17	0,09	-0,02	0,29	-0,20	0,29	-0,07	1,00				
12	VW rotation matched own sense of direction	0,17	-0,10	0,29	-0,07	-0,03	-0,08	0,27	0,01	0,13	0,42	0,26	1,00			
13	Difficulty to stay on track	0,18	-0,22	0,06	0,07	-0,10	-0,17	-0,36	0,10	0,02	-0,20	-0,22	-0,11	1,00		
14	VW rotated logical	0,00	0,06	0,35	-0,02	-0,27	-0,37	0,32	-0,19	0,12	0,41	0,19	0,69	-0,05	1,00	
15	Regularly plays mobile games	0,26	-0,21	0,53	-0,20	-0,38	-0,39	-0,04	-0,13	0,23	-0,06	-0,14	-0,07	0,62	0,06	1,00

Figure 17: Correlation matrix between data from the application and answers on the questionnaire. Notable correlations have been marked blue.

The other main task of the experiment was for players to aim and shoot at the targets they encountered along the way. This task relied mostly on the implemented compass. After players were notified about an upcoming target they were required to respond quickly when the target appeared, while still trying to be as accurate as possible in order to receive a better score. By looking at the data from the application we can determine how well our subjects performed.

The players required an average of 11.125 shots per session, meaning that they needed 1.85 shots per landmark. The total average accurracy of all shots was 7.4 degrees. The accuracy is determined as the angle between the aiming direction and the line from the player to the landmark. For the experiment a cone of 18° was used, therefore a shot with an accuracy of $< 9^\circ$ was a hit. Figure 18 shows a histogram of all the shots that have been fired during the experiment by the users. As seen, most shots are within the range of [0..9] degrees. The number of shots that are further off steadily decreases. Even shots that missed only missed with an additional average 4.95 degrees. These results show that the task of shooting the targets is very feasible.

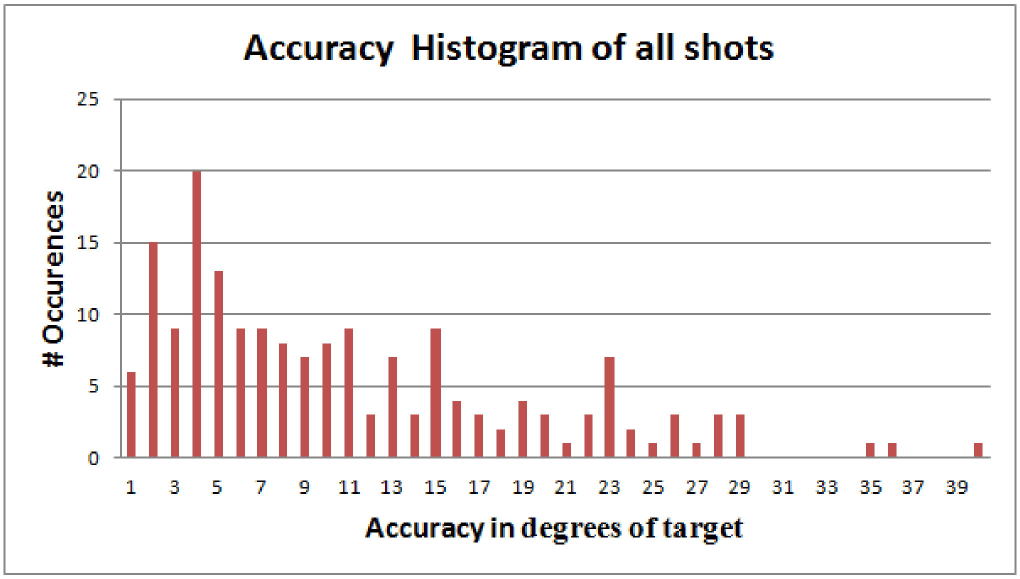


Figure 18: Histogram of the accuracy of all the shots during the experiment

When looking back at the correlation matrix we can draw more conclusions. People who indicated that they could imagine where a virtual object would be located in the real world also scored better according to the correlation of 0.58 between the variables, indicating that people who could better translate the virtual world to the real world also managed to shoot better and thus score more points. Another correlation of 0.58 is found between the average accuracy and the indicated by players aiming difficulty, which is a correlation that could be expected. In a similar manner we would expect a high negative correlation between the score and the indicated aiming difficulty. However, this correlation is only -0.33, but can be explained by the penalty on a slow reaction time, as subjects who aimed accurately could have taken too long with shooting and therefore still receive a low score for the hit. The most expected correlations are the correlations of -0.61 and 0.74 between the average accuracy, and the subject's score and necessary attempts respectively, and the correlation of -0.79 between the number of shots and the score, as fewer shots increases the score.
It did seem that people who are familiar with mobile games had an advantage as they scored better according to the correlation of 0.53 between these variables.

7 Conclusion and Discussion

In this section we will discuss our results from the experiments in Sections 5 and 6 along with the research questions from Section 3. As some of the questions are answerable by the first experiment we will address those first.

- What is the best method to implement a digital compass on a mobile device, and how much does it vary between devices?

We discussed several approaches to implement a compass in Section 4.3 and examined them with the experiment from Section 5.1.1. The results of this experiment can be found in Section 5.2.1 and show us that the Sensor Fusion approach delivers the best results. This approach combines multiple sensors from the mobile device to learn the device's orientation and let sensors data correct each other. Unfortunately, even this approach suffered from a slight imprecision when compared with an analogue compass, and is also dependent on the hardware as it differed between different mobile devices. Therefore, a margin of error is expected and must be taken into account when applied in applications.

- How well does GPS in mobile devices perform, and how much does it vary between different devices?

The GPS receiver has been examined with the experiment from Section 5.1.2 and its results can be found in Section 5.2.2. The experiment tested the precision of the GPS location tracker and showed it could be precise up to a few meters, but is also dependent on the device with different devices showing different results. The best results only had a variation of 2.62 meters between received locations of the same position. However, such an inconsistency is still unacceptable for applications where more precision is required, such as a multi-player shooter.

Data from the user study in Section 6 showed that for some tasks, such as following and staying on a path, the GPS worked with a low error rate. This is probably because the precision is better for location data that is collected one after another, rather than the measured precision of the locations during the experiment where the location tracker moved away and back to the same location and contained a time interval. This is ideal for a single player game, for even when the measured location of a user is inaccurate within a few meters, all the following location updates will include approximately the same error. This does not influence the player who will perceive the series of location updates to be almost consistent with his own experience.

- How well does the combination of the compass and GPS feature perform?

When both our major components are combined in an application we expected the performance to decrease as a result of the combined inaccuracy of the components. The combination has been tested in the experiment in Section 5.1.3 and the user study from Section 6. Their results can be found in Sections 5.2.3 and 6.2 respectively.

The first two scenarios discussed in the GPS and Compass combined experiment clearly shows a decline in the performance when we needed to rely on more factors, each with their own risk at incorrectness in their data. When working towards a multi-player game, where multiple devices rely on the components to be exact, these problems need to be tackled first.

However, the last scenario of this experiment, and the results from the user study show that when the player is required to shoot at virtual targets with locations relative to the player, the task becomes more attainable. The results still included a margin of error, but this can be taken into account when a shot is defined as a cone, covering a wider area to be hit.

- How do people experience an implementation of an Orientation-Aware Location-Based Game?

In our user study from Section 6 we let subjects carry out an experiment in the shape of a game where they put the collaboration of the GPS and compass to the test. Besides the results from the application itself we also collected the responses of the subjects about the game with a questionnaire, because we are interested in how a user would experience it. The results can be found in Section 6.2.

From the questionnaire we learned that the subjects responded very positively to the application. They enjoyed playing the game very much and expected the technology to be used in future games. They agreed with a lot of the feedback the device returned about their actions and thus agreed mostly with how the application functioned. On tasks they experienced as less successful the data showed that these were also carried out with a higher error rate. When subjects become more familiar with such an application they might perform and evaluate it even better.

With these questions answered we can attempt to tackle our main question.

- What is the feasibility of an Orientation-Aware Location-Based Game?

Before we answer this question, we must realise that this also depends on the type of game that is to be designed. We learned from the results of our experiment in Section 5.1.3 that when multiple components in the game have an error in their data, it will decrease the performance, as the total inaccuracy is amplified by the inaccuracy of the individual components. Therefore, a game which relies on many components operating very accurate and precisely seems not to be possible with the tested technology. This also corresponds with the work of Hall and Janisz [39], who researched the required capabilities of the sensors. Even though sensors have improved over the years, it seems that they still do not meet those requirements. A game with a multi-player component would be very challenging, for when 2 devices both have a rather small error of 2 meters to their exact location, the combined error could be 4 meters. When this is the case players would constantly be misguided about each others location resulting in a terrible gaming experience, even when some margin of error is taken into account. There are of course more issues besides this matter. For example, we did not even discuss the issues that lie in connecting and synchronizing multiple devices adding up to the chance of inaccurate performances.
However, when we considered a less complex game, the results were more promising. When the location of the virtual targets no longer relied on exact data from the location sensor, but became relative to the user, it diminished the number of problems caused by the inaccurate components. The exact location of the user according to the GPS receiver still can be incorrect, but as the virtual world is relative to the user, is this not a major issue. For the user study in Section 6 a game-like application was developed where players received tasks to be carried out using the GPS receiver and implemented compass. The data from Section 6.2 showed that these tasks were very realizable by the test subjects. When taken into account, the amount of inaccuracy was not sufficient to make the game impractical. From the questionnaire we also learned that subjects enjoyed playing the game and expected the technology to be incorporated into future games. From this we conclude that with the current technology it is possible to create a game that is both location- and orientation-aware, as long as it is in a format similar to the game from the user study. A more advanced game with multiple players each carrying a device seems more challenging.

- What needs to be improved when working towards an Orientation-Aware Location-Based Game?

One of the major problems was the lag during each location update. As the current GPS receivers in mobile devices only have an update rate of once per second, the subjects indicated that this sometimes caused them to diverge from the path or miss a target when their position unexpectedly updated. Better but external GPS receivers belong to the possibilities to increase the update rate to 5 times per second. In the future better internal GPS receivers might be possible. However, they are a huge drain on the battery life span. The final experiment was carried out with targets that had a location relative to the player's location, decreasing the inaccuracy. We envision a game where more players compete with each other. This would result in players aiming at each other and not at the dot shown on their devices. To make this work the locations of each player should not only be very accurate and consistent, but also take into account delays in the updates and communications between devices.
Even in the Sensor Fusion approach the digital compass suffered from inaccuracy. We realized that the Sensor Fusion approach was the best method from the methods we tested, but other

approaches could also be possible. The Sensor Fusion approach uses an algorithm where improvement could be possible. A more direct improvement would be better sensors that have less noise in their data. A decrease in the inaccuracy from the magnetometer, accelerometer, or gyroscope would result in a better performance by the Sensor Fusion method.

From all our experiments we conclude that mobile games can become aware of a player's location and orientation and result in an enjoyable gaming experience. The required sensors do suffer from inaccuracy restricting the possibilities, but do not limit the entire concept. Future advancements in the technology and hardware could resolve some of the problems, opening up the way to even better Orientation-Aware Location-Based Games. For now the games should be limited to include tasks were a margin of error is acceptable in the data from the used sensors.

8 Future Work

In this thesis we tested multiple components of mobile devices. In a user study an application using a combination of these components was put to the test. The application was a simple Orientation-Aware Location-Based Game, the main topic of this project. The technique towards such a game has been tested in the form of a straightforward shooter game. The application in this shape produced good results showing that there are tasks possible that utilize the GPS and compass features of a mobile device. The kind of tasks, however, were limited to the application. In a future application other and more extensive tasks could be added and tested. For example, we have limited ourselves to static targets and created a setting where users would walk in a relaxed pace.

We noticed that faster players had more trouble in carrying out the GPS related tasks. In a follow-up experiment the impact of players with increasing velocities could be tested, in order to find out if a game that requires players to move with speed would still be feasible. In its current format the virtual targets did not move. By adding motion to targets a new level of difficulty is achieved and it is expected that the difficulty of hitting targets will increase, but research is necessary to conclude to what extent.

We condemned complex multi-player games on the fact that the required accuracy is too high for too many components, resulting in too many errors. However, this does not have to exclude all multi-player games. We could envision a one-on-one game where users battle over the same virtual targets and objects. A discrepancy between the perceived locations of the users could diminish the experience, but does not take away the playability directly, as the virtual targets would still be relative to each of the players. It could be extended to more players when it is found to be feasible.

During this thesis we limited ourselves to the compass and GPS features, but mobile devices have a range of other sensors included. Other research could discover other sensors to be practical as additional game components, to make the application aware of even more aspects of the user.

Finally, we have consistently pointed out that this research is based on current mobile devices. However, the mobile devices industry creates better hardware and new innovations every year and the devices used during the experiments are not from the newest generation. In the future this research could be repeated with better devices with improved hardware, in the hope that some of the current issues have been dealt with.

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